S5-18

219951

138

N90-19254

LARGE-DIAMETER GEOSTATIONARY MILLIMETER WAVELENGTH ANTENNA CONCEPT

W. S. Gregorwich,
H. A. Malliot, and
A. K. Sinha
Lockheed Missiles and Space Company, Inc.
Sunnyvale, California

CURVED REFLECTING SURFACE

The concept of a curved reflecting surface by means of an electrostatic membrane appeared as early as 1932 in the British patent (830,473) by Muller. Recent articles (refs. 1,2,3,4) propose the use of the electrostatic membrane in space applications as large-reflector antennas.

A schematic of the concept is shown in Fig. 1. The rigid command surface approximates the desired shape and contains electrodes. The flexible metallized reflector is the electrostatic membrane. By means of bias and control voltages between the membrane and command surface electrodes, the membrane is distended into the desired shape. An optical measurement system provides the feedback data necessary for computer figure control.

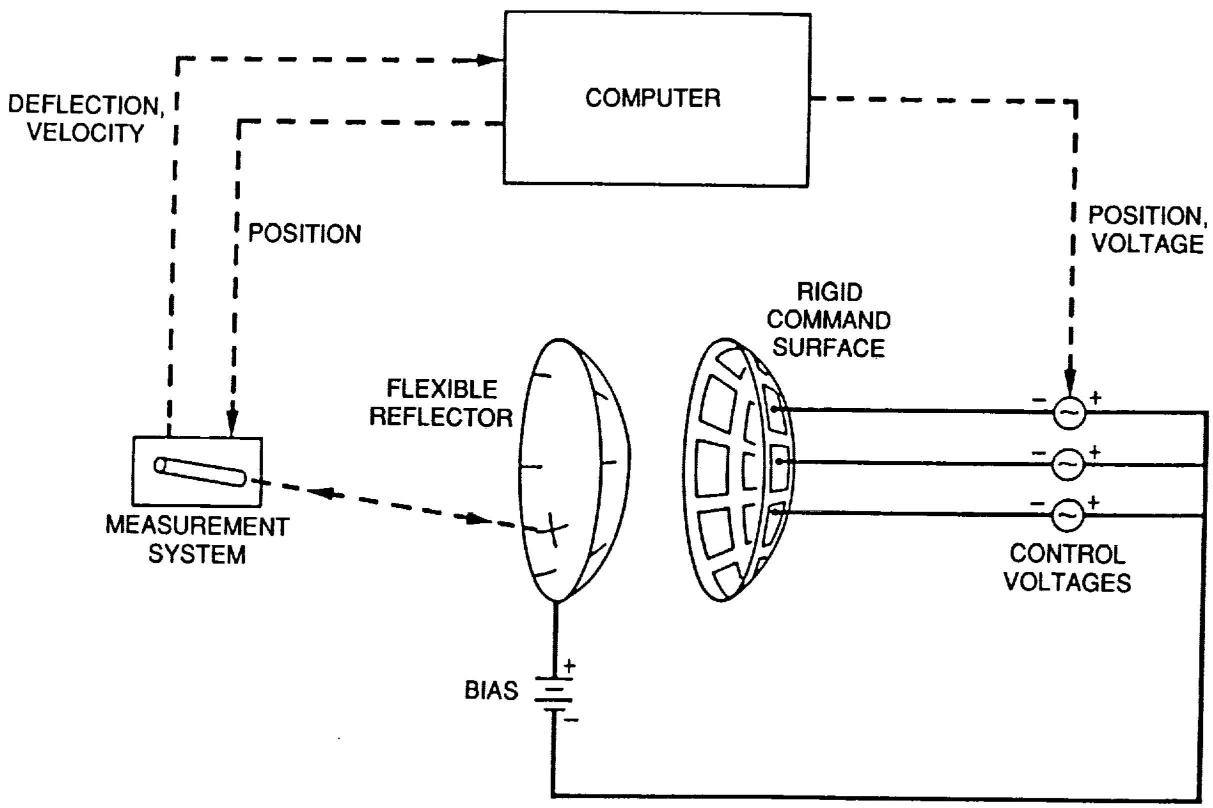
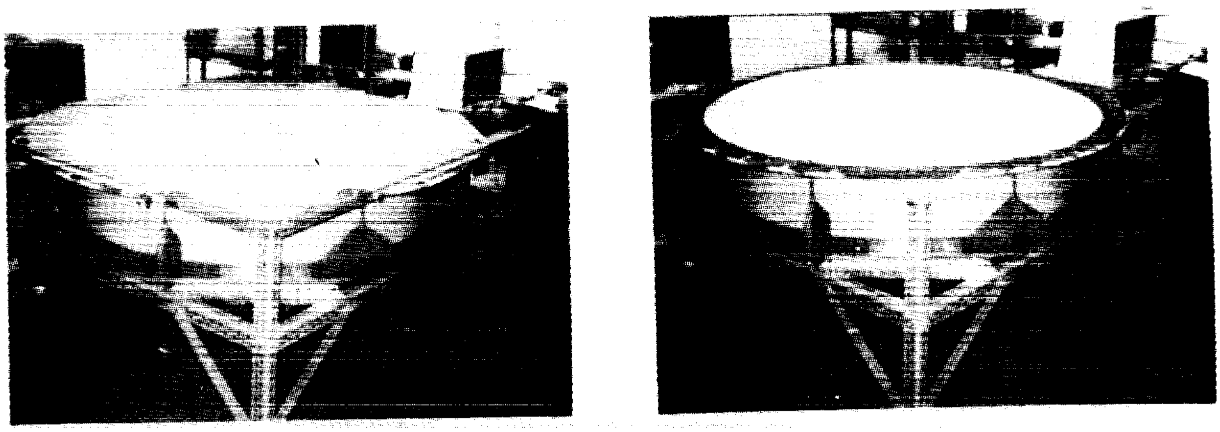


Figure 1

ELECTROSTATICALLY SHAPED REFLECTOR MODEL

Figure 2 shows a 2-m-diameter electrostatic membrane experiment performed by MIT (ref. 2) and sponsored by Lockheed. Lockheed is presently using electrostatic membrane techniques on high-precision laser mirrors (ref. 5).



a. Relaxed Membrane   b. Formed Paraboloid

Figure 2

ELECTRODES

The MIT study demonstrated that it does not take many electrodes to form a large precise reflector. It can be seen from Fig. 3 that for a 10-m-diameter antenna (D) with f/D = 1.0 and a root mean square (rms) error ϵ of $\lambda/50$ (where λ = free space wavelength) and $D/\epsilon = 10^6$, one requires only N = 40 electrodes at 220 GHz. Due to the wide influence of a single electrode, few are needed.

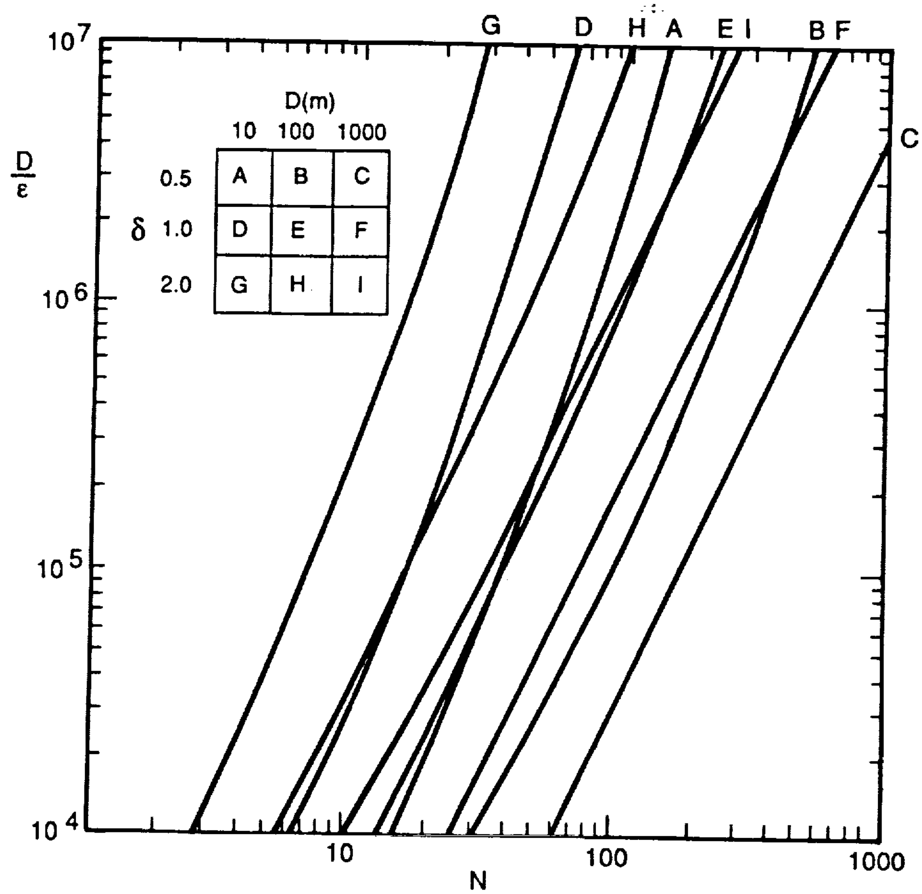


Figure 3

ADVANTAGES OF WRAP-RIB

The NASA Langley Study (ref. 3) demonstrated that for 1-mm rms on a 100-m-diameter antenna only 220 electrodes are required. The report found that the critical design parameters are packaging volume and weight, parts count complexity, and rf performance enhancement. The report found that the wrap-rib design could be used for the command surface and had the salient features of:

- Flight proven hardware
- Lightest weight - only 24 ribs for 100 m diameter at 5 GHz
- Smallest structural packaging volume
- Low total parts count

WRAP-RADIAL-RIP COMMAND SURFACE

The concept of employing the wrap radial rib as the command surface is depicted in Fig. 4. Instead of attaching the metallic mesh on the concave side of the ribs, as normal, the mesh is attached to the convex side and thereby acts as a bottom shield for the electrodes. The membrane acts as the upper shield, thus forming a protective Faraday cage to protect the electrodes from cosmic particles and other space debris. There is a central hub opening to allow the deployment of the feed and optics support structure.

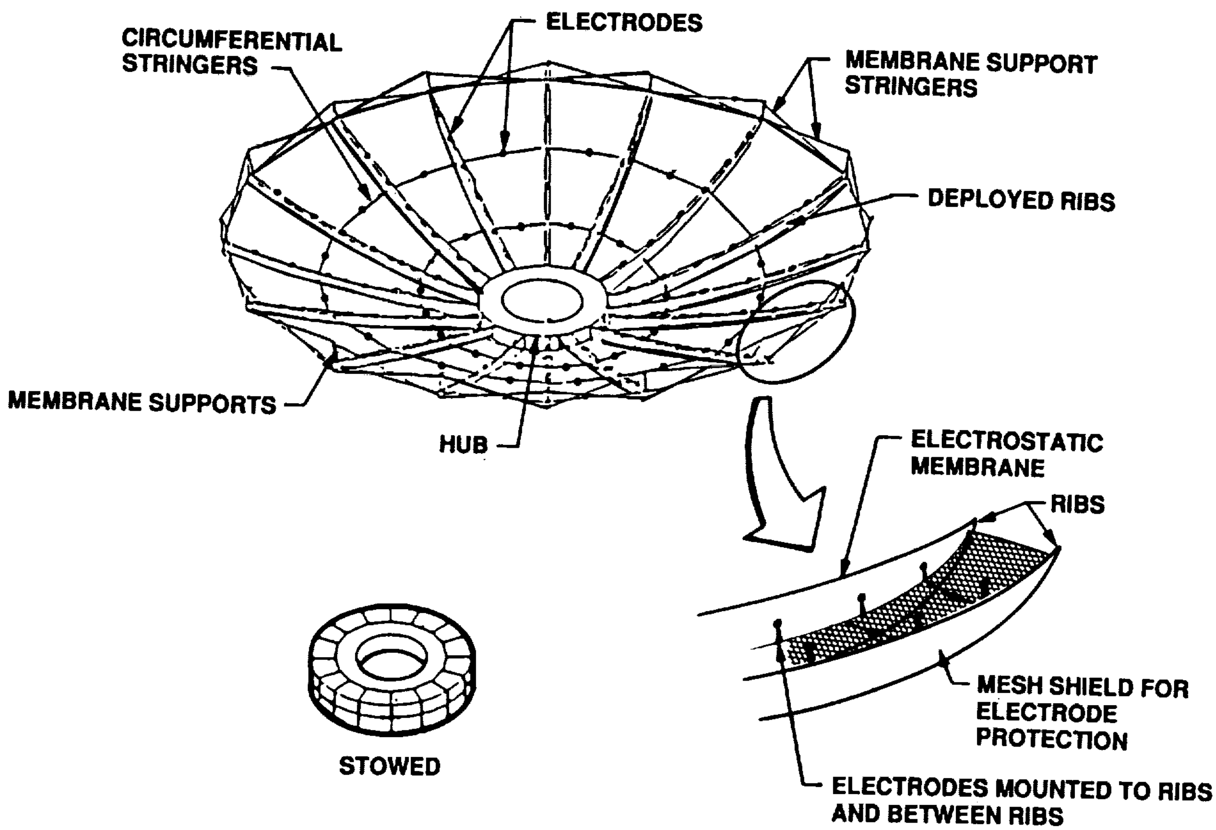


Figure 4

The optical system that senses the slope of the membrane is depicted in Fig. 5. It is located above the 0.2-m-diameter array feed. A two-axis scanning mirror scans the slope measurement beam over the membrane surface. A continuous scan in a spiral pattern from the outer edge to the center and continuing in the same direction from the center to the outer edge avoids vibration producing accelerations, minimizes cost, and maximizes reliability. Strong signals are received only when the beam scans over selected sample points where reflective material has been deposited on the membrane. The locations of sample points can be determined from angle resolvers in the scanner or, alternatively, bar codes similar to those used with point-of-sale scanners in supermarkets can be placed adjacent to the sample points.

The membrane slope is measured by using sideband interferometry. A plane-wave laser beam is split to form a reference beam and a membrane illumination beam. A pair of mirrors folds the reference beam onto an imaging sensor at a fixed angle. A partially reflective mirror directs the membrane illumination beam onto a two-axis scanning mirror which directs the beam onto the membrane where it is reflected by diffuse reflective material (e.g., used on projection screens) deposited on the membrane. The membrane illumination beam has a plane wavefront with constant phase over its cross section, but due to the membrane slope the reflected signal beam will have a linear variation of phase over its cross section. Membrane curvature within the area of illumination will also cause variation of the signal beam phase but this can be kept negligible by using a small illumination beam diameter. Part of the incident illumination forms a signal beam incident on the two-axis scanning mirror and is reflected toward the imaging sensor. Interference between the signal beam and the reference beam will produce a fringe pattern with fringe periodicity dependent on the angle between the two-beam wavefronts. Fourier analysis will provide measurement of fringe frequency which is related to the membrane slope by simple geometry.

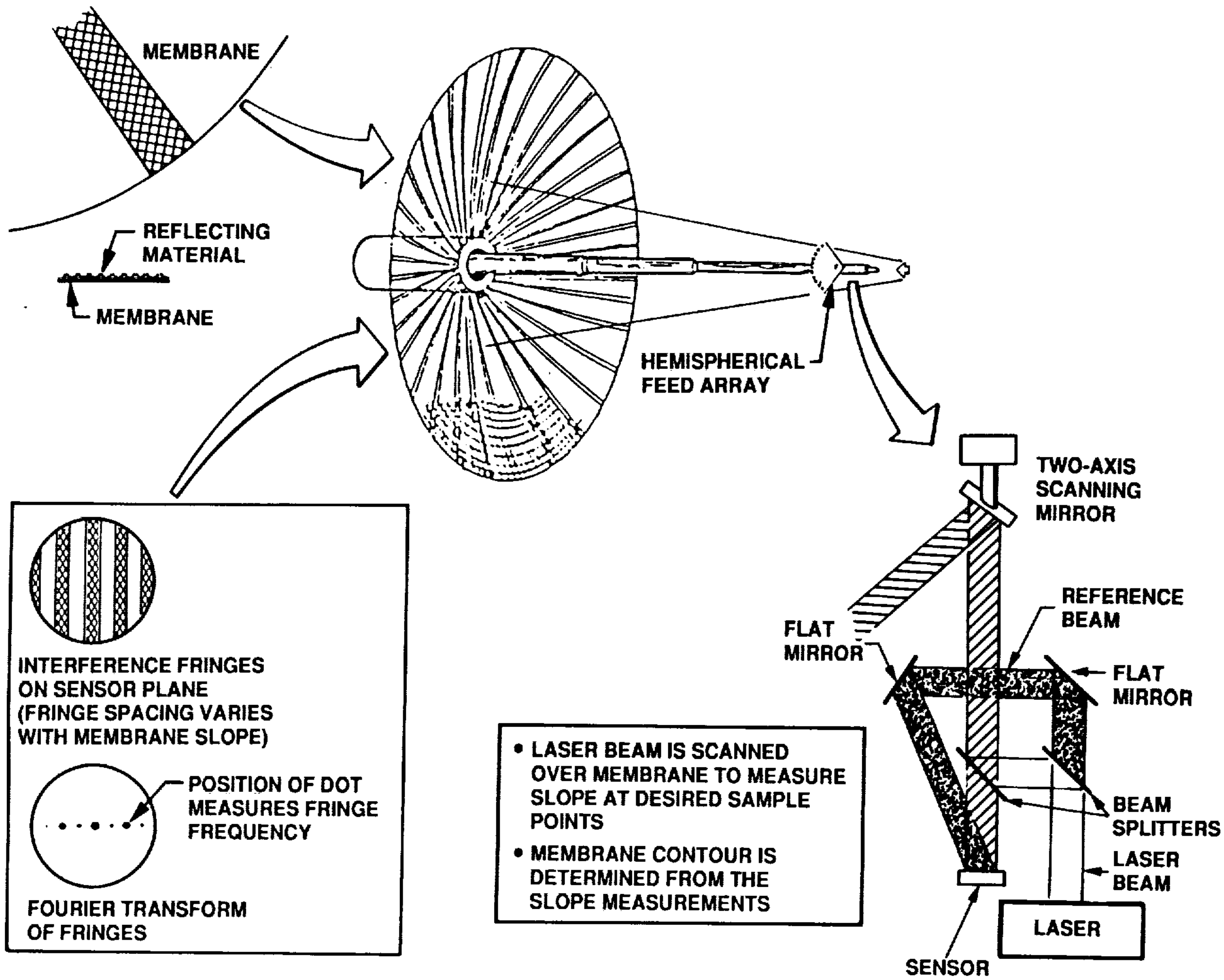

MEMBRANE
REFLECTING
MATERIAL
MEMBRANE
HEMISPHERICAL
FEED ARRAY
INTERFERENCE FRINGES
ON SENSOR PLANE
(FRINGE SPACING VARIES
WITH MEMBRANE SLOPE)
POSITION OF DOT
MEASURES FRINGE
FREQUENCY
FOURIER TRANSFORM
OF FRINGES
TWO-AXIS
SCANNING
MIRROR
REFERENCE
BEAM
FLAT
MIRROR
FLAT
MIRROR
• LASER BEAM IS SCANNED OVER MEMBRANE TO MEASURE SLOPE AT DESIRED SAMPLE POINTS
• MEMBRANE CONTOUR IS DETERMINED FROM THE SLOPE MEASUREMENTS
BEAM
SPLITTERS
LASER
BEAM
LASER
SENSOR

Figure 5

MEMBRANE CONTROL CONCEPT

A feedback control system shown in Fig. 6 is used to minimize the effects of disturbances and to maintain stability. Feedback is based on sensing the membrane slope. Slope data are used to compute the membrane contour. This contour is compared to the desired contour, and voltage adjustments to correct the contour are computed. A voltage controller then adjusts the electrode voltages to the required values. Slope measurements will be corrupted by noise, so smoothing and filtering is used to obtain minimum mean-square-error estimates of slope. The control voltage adjustments are computed to minimize mean square error in control and ensure stability.

The closed-loop dynamic control system will operate in an unstable condition and can incorporate VHSIC technology.

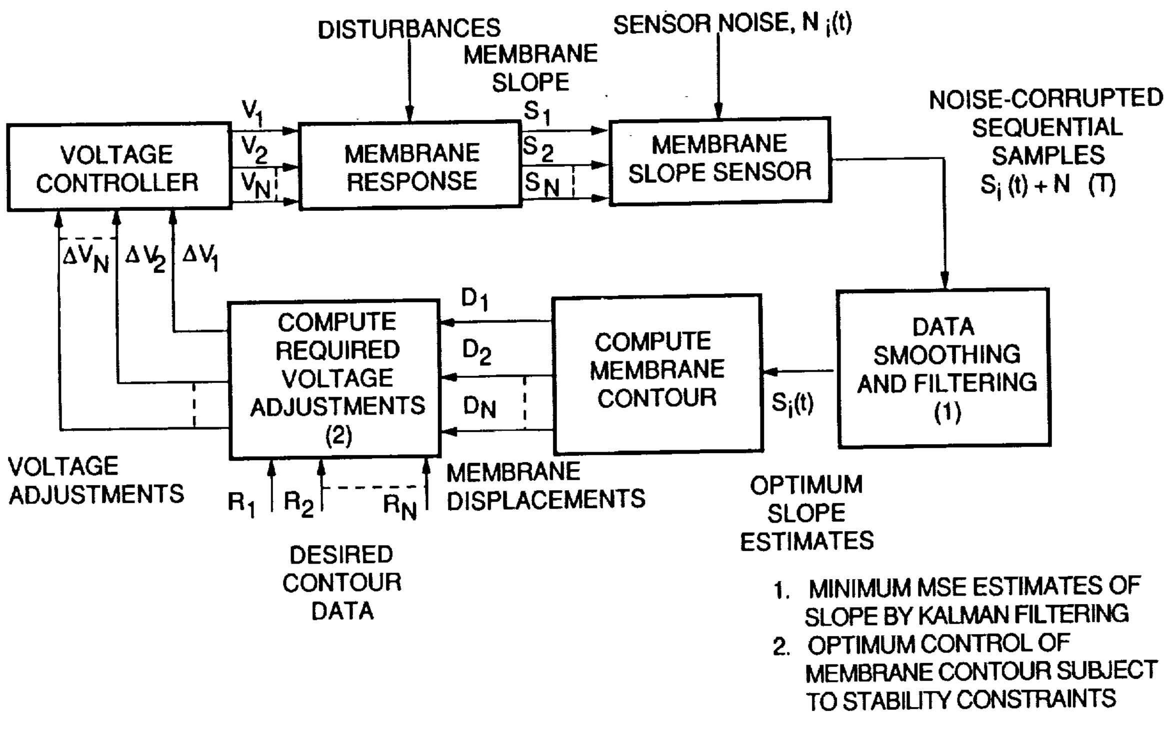


Figure 6

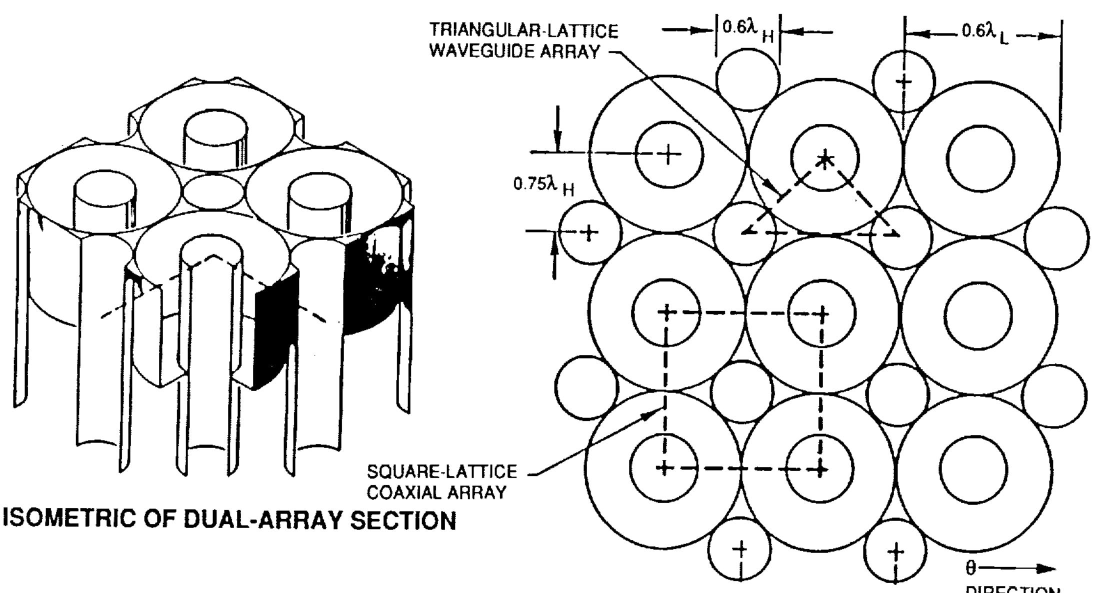
DUAL-BAND ELEMENTS

To obtain electronic off-axis scan, the dish must be spherical. Parabolic dishes only allow a 10-beamwidth scan for 90% main-lobe efficiency. To scan a spherical dish, the prime focus feed must be either a line source linear array or a hemispherical cluster array as shown in Fig. 5.

The array will consist of dual-band elements depicted in the figure for a Millimeter Wavelength Reflector (ref. 6). The high-band, circular-waveguide elements nested between and within the coax low-band elements will receive energy over the H_2O, and window frequencies of 183 and 220 GHz, respectively. The coax element will receive energy at the O_2, and window frequencies of 60 and 90 GHz, respectively. The mid-band separation ratio of 2.6 (i.e., 200 GHz/75 GHz) is identical to the optimum packing ratio, thus avoiding grating lobes.

The coaxial-array element flown on the Viking deep-space mission will receive all senses of polarization.

It is also possible to include the bands below 60 GHz in the configuration of Fig. 5. By placing an additional cassegrain feed on the central mast with a shuttle tile support mast replacing he graphite-epoxy mast in front of the feed. The tile has a dielectric constant of 1.07 which is essentially transparent to the rf energy and will mechanically support a frequency-selective cassegrain subreflector placed in front of the millimeter wave spherical prime-focus feed of Fig. 7.



ISOMETRIC OF DUAL-ARRAY SECTION

HIGH-BAND WAVEGUIDE ARRAY INTERLACED WITHIN LOW-BAND COAX ARRAY

Figure 7

MILLIMETER WAVELENGTH REFLECTOR

The shuttle tile may also be used to fabricate a rigid, thermally stable 4.4-rm diameter dish. The amorphous S_iO_2 tile material has the lowest coefficient of thermal expansion for a space-qualfied material having a high strength to low mass ratio. A 1 lb, millimeter wavelength reflector that operates from 60 to 90 GHz and fabricated from third-generation shuttle tile is shown in Fig. 8. It has survived a random vibration of 24 g rms.

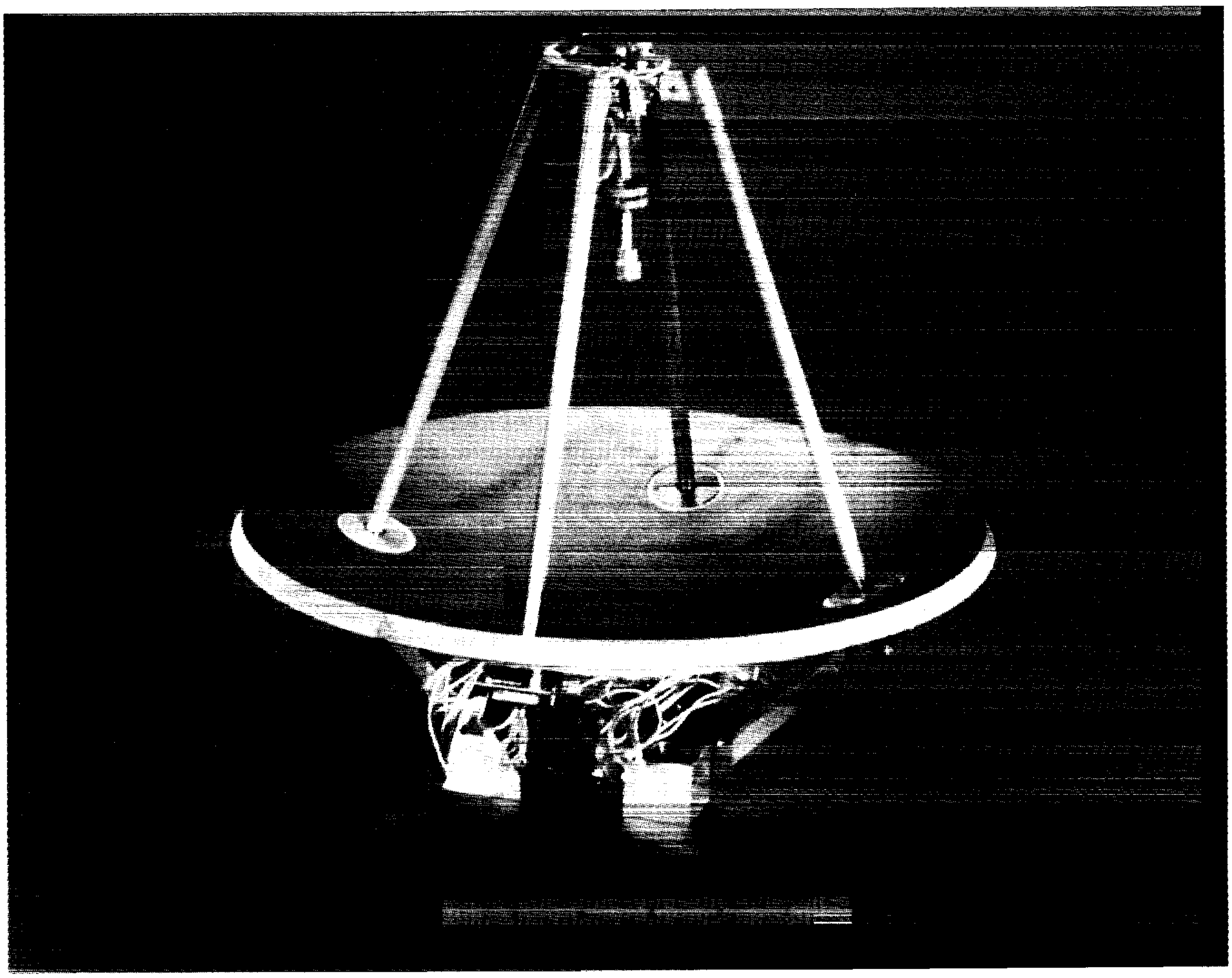


Figure 8

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

ORIGINAL PAGE IS
OF POOR QUALITY

PROOF OF CONCEPT AND DEMONSTRATION MODEL

In conclusion, the wrap-rib, electrostatic-membrane reflector is several orders of magnitude lighter than the nondeployed rigid reflectors and does not have an aperture constrained by the 4.4-m diameter of the launch vehicle envelope.

It is recommended that a scaled demonstration model be fabricated from space-qualified materials and tested for the space environment as follows:

- o Use existing 2-m-diameter wrap-rib and space-qualified materials for design and development of electro-static membrane
- o Test laser sensor and control system
- o Perform control near-field RF test
- o Perform thermal vacuum test
- o Perform final near-field RF test

REFERENCES

1. Mihora, D.J., Precision Low Mass Membrane Antenna, IEEE Military Microwaves '80, October 1980, pp. 344-349.

2. Lang, Jeffrey H. and Staelin, David H., Electrostatically Figured Reflecting Membrane Antennas for Satellites, IEEE Trans on Automatic Control, Vol. 27, No. 3, June 1982, pp. 666-670.

3. Brook, A.L., et al, Conceptual Design and Analysis of a Large Antenna Utilizing Electrostatic Membrane Management, NASA Contractor Report 3522, May 1982, p. 312.

4. Goslee, J.W., et al, Electrostatic Forming and Testing of Polymer Films on a 16-Foot-Diameter Test Fixture, NASA-TM-86328, Feb 1985, p. 34.

5. Calflin, E. Scott and Bareket, Noah, Configuring an Electrosatic Membrane Mirror by Least-Squares Fitting with Analytically Derived Influence Functions, J. Optical Society of America A, Vol. 3, November 1986, pp. 1833-1839.

6. Gregorwich, W.S., A Multipolarization Dual-Band Array, 1975 IEEE International Antennas and Propagation Symposium, pp. 189-192.